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NASA TM X-71916

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(NASA-TM-X-71916) THE REQUIREMENTS FOR
BATTERIES FOR ELECTRIC VEHICLES (NASA) 7 p
HC \$3.50 CSCL 10C

N76-21701

G3/44 25219
Unclas

**THE REQUIREMENTS FOR BATTERIES
FOR ELECTRIC VEHICLES**

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TECHNICAL PAPER to be presented at
Twenty-seventh Power Sources Symposium
Atlanta City, New Jersey, June 21-24, 1976



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INTRODUCTION

Renewed interest in electric vehicles stems from the desire to reduce the nation's petroleum consumption. While early widespread use may come from delivery trucks, a sizable impact on oil use can only come from using electrics to replace conventional cars for personal transportation. Three factors determine the size of the impact: the market potential for electrics, the date of introduction, and the rate of consumer acceptance. Reference is frequently made to the analyses of battery energy and power requirements made by Ragone.^(1,2) He concluded that "present commercial batteries cannot provide both high power levels and high specific energy required for long range." These conclusions arise because Ragone studied cars with long-range, high-speed highway cruising capabilities. Other workers⁽³⁾ have also concluded that advanced batteries are required before electric cars can meet user needs. They assume rapid market acceptance once these batteries are developed. This paper reassesses the role of electric vehicles in our transportation system and their potential impact on oil consumption.

MARKET POTENTIAL

The estimated market potential of the electric car depends on the role assigned to it in the national transportation system. Ragone's emphasis on range contained an implicit assumption that the farther a car goes, the greater its value to its owner. It seems more realistic to assume that utility will increase with range to the point where intra-city travel needs are satisfied. Any increase beyond that point will not increase the car's value until full intercity capability is achieved. This is well beyond the capability of even the most energetic batteries under development. Therefore, the major early market for electric cars will be in households of two or more automobiles. There are already approximately 26 million second and third cars in U.S. households.⁽⁴⁾ This represents a minimum target market since some sales to single-car households will occur.

INTRODUCTION DATE

The year when electric vehicles are available to the consumer depends on when batteries are developed which satisfy the requirements for an urban car. There are three distinct levels of battery technology which could be commercially available at different times and will result

in different vehicle performance capabilities. These are summarized in table 1. The "practical" range shown is the daily travel accommodated with a reasonable margin (assumed to be 15%) and is used to measure the usefulness to the owner. Near-term batteries are the lead-acid and its derivatives which are expected to deliver 22 to 40 watt-hours per kilogram (10 to 18 Wh/lb). Midterm batteries are now in a relatively advanced state of development but require additional work before being offered commercially. The nickel-zinc, nickel-iron, and iron-air systems are in this class with projected energy densities of 66 to 110 watt-hours per kilogram (30 to 50 Wh/lb). Far-term batteries offer energy densities of 154 to 220 watt-hours per kilogram (70 to 100 Wh/lb), and are in the laboratory research stage today.

Range requirements for urban cars have been developed by the author⁽⁵⁾ using automobile use patterns contained in the National Personal Transportation Study. The results are shown on Fig. 1 where the "usefulness" is the percentage of days of a year when the driver travels the distance shown or less. The simulation shows that a daily driving range of 82 miles meets the requirements of the public on 95 percent of the days of the year, which is the criteria established by Naidu⁽⁶⁾ for a successful electric automobile. In addition, the simulation makes it possible to estimate the extent to which vehicles with lesser or greater ranges can satisfy user needs. The near-term vehicle will be useful 81 percent of the time, the midterm 95 percent of the time, and the far-term 98 percent.

MARKET GROWTH RATE

The published electric vehicle sales forecasts^(1,6,7,8) shown on Fig. 2, except for Naidu's, appear to be derived by estimating the market and assuming full penetration in time to produce the desired impact. Wenz and Eyrich⁽⁹⁾ have shown that sales of new technological products follow a definite pattern, an S-shaped curve described by the Gompertz Function, $Y = Ka^{b^x}$, where Y is the cumulative sales after x years in a market with potential sales of K units. The relationship is shown on Fig. 3.

Three separate calculations were made starting at different years and using an initial sales level of 10,000 units. A maturity period of 20 years was selected by studying the penetration rate of imported cars into the U.S. market. Market penetration was assumed to be proportional to usefulness except for the near-term car where the lower usefulness would probably greatly reduce penetration. Here, 50 percent of the third-car and 25 percent of the second-car markets were assumed, resulting in a potential market of 8.7 million. The total vehicles on the road each year to the year 2000 was calculated. Assuming that the automobiles replaced burn gasoline at a rate of 0.04 gallons per mile (25 mpg), each electric car on the road will save approximately 407 gallons of gasoline per year, equivalent to 19.4 barrels of petroleum. This savings was then

reduced to include only nonpetroleum electricity generated each year, based on ERDA projections.⁽¹⁰⁾

The effect of developing all three types of batteries simultaneously was also determined. As each new technology appears, its growth curve was calculated from where the previous one ended. The results of the analysis are shown on Fig. 4 and in table II. When single technologies are considered, the mid-term battery shows the largest savings, averaging almost a half million barrels per day despite the fact that introduction does not occur until 1982. The lower performance of the long-term vehicle results because its market potential is only slightly higher than the mid-term battery which enjoys a four-year time advantage. If extrapolated beyond the year 2000 the long-term system would eventually show a slightly larger savings. When all three technologies are introduced sequentially, a savings increase of about 25 percent over the best single result is produced.

CONCLUSIONS

The analysis of automobile use patterns shows that the battery requirements for an urban car can be met by mid-term battery technology. The far-term technology potentially offers greater range but this does not proportionately increase the usefulness of the vehicle to its owner. This suggests that the research and development emphasis on far-term batteries should be shifted toward more modest energy density goals, if such a shift eases technical problems and allows the use of lower cost materials and construction methods.

If the technology diffusion model accurately portrays the rate at which the public will adapt electric cars, the impact of the mid-term batteries by the year 2000 will be greater than that of the far-term batteries because of their earlier introduction and nearly equal market potential. From the standpoint of maximizing both the cumulative impact and the benefits derived in the year 2000, however, a strategy of early introduction of near-term and mid-term cars followed by the far-term vehicle produces the optimum result.

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TABLE I. - VEHICLE RANGE AND AVAILABILITY FROM
DIFFERENT BATTERY TECHNOLOGY LEVELS

Battery technology levels	Daily driving range (km/mi)		Available in (yr)
	Maximum	Practical	
Near-term	80/50	68/43	1978
Mid-term	161/100	137/85	1982
Far-term	322/200	274/170	1986

TABLE II. - IMPLEMENTATION RATES FOR VARIOUS BATTERY TECHNOLOGIES

Technology	Near-term battery car	Mid-term battery car	Far-term battery car	Combined battery technologies
Cumulative oil savings (millions of barrels, 1978-2000)	1954	3733	2228	4983
Average annual savings (millions of barrels)	89	170	101	227

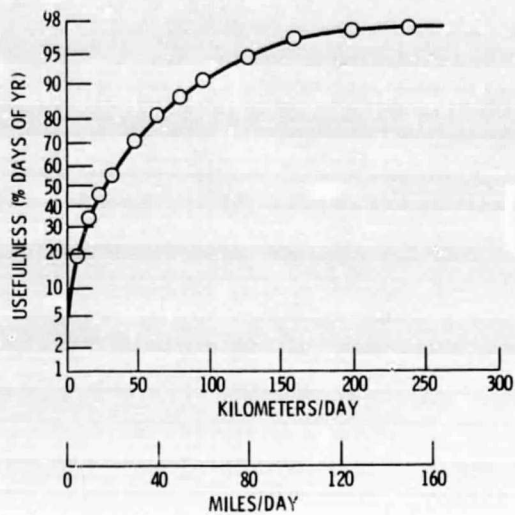


Figure 1. - Monte Carlo simulation of automobile use patterns.

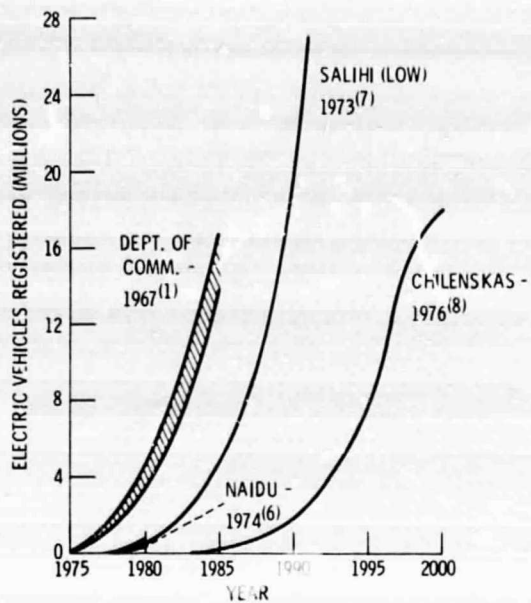


Figure 2. - Electric vehicle market forecasts.

$$Y = Ka b^x$$

$$a = \frac{\hat{y}_0}{K}$$

$$b = \left[\frac{\left(\log \frac{\hat{y}_m}{K} \right)}{(\log a)} \right]^{1/m}$$

$$\frac{\hat{y}_m}{K} = 0.95$$

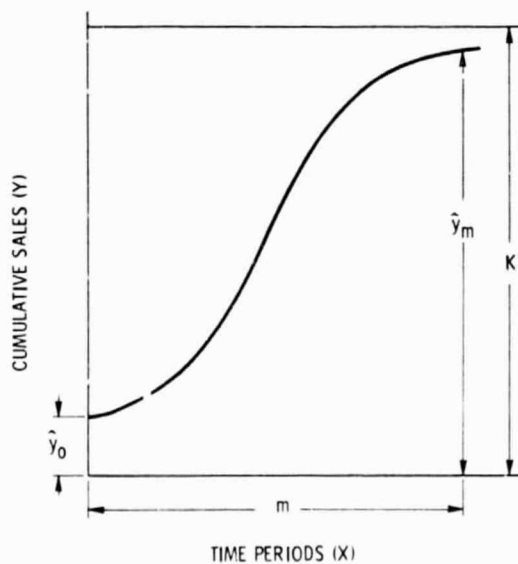


Figure 3. - Gompertz function.

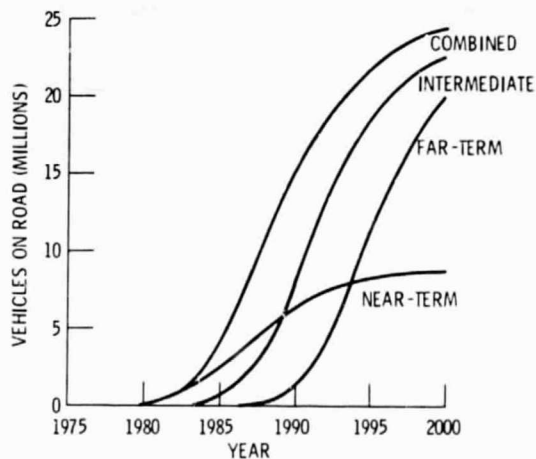


Figure 4. - Electric vehicle market growth models based on different battery technology levels.